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The hidden Higgs model at LEP2 [1]

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Abstract

The influence of massless scalar singlets on the Higgs signal at LEP2 is discussed. It is shown that for strong interactions between the Higgs boson and the singlet fields, detection of the Higgs signal can become impossible.

[1] Contribution to the Workshop on Physics at LEP2.

1 Introduction

The radiative corrections at LEP1 depend only logarithmically on the Higgs mass, and the measurements, although very precise, are not sufficient to determine the structure of the Higgs sector. It is therefore necessary to keep an open mind to the possibility that the Higgs sector is more complicated than in the Standard Model. Beyond the Standard Model various extensions have been suggested. One of the possibilities is supersymmetry which is discussed in a previous section. Another possibility is strong interactions in the form of technicolor, which at least in its simplest form is ruled out by the LEP1 data. Strong interactions in the Standard Model itself imply a heavy Higgs boson and can presumably be studied at the LHC.

However the idea of strong interactions is more general. In particular it is possible that strong interactions are present in the singlet sector of the theory. In general the choice of representations in a gauge theory is arbitrary and presumably a clue to a deeper underlying theory. Singlets do not have quantum numbers under the gauge group of the Standard Model. They therefore do not feel the strong or electro–weak forces, but they can couple to the Higgs particle. As a consequence radiative corrections to weak processes are not sensitive to the presence of singlets in the theory, because no Feynman graphs containing singlets appear at the one–loop level. Because effects at the two–loop level are below the experimental precision, the presence of a singlet sector is not ruled out by any of the LEP1 precision data.

It is therefore not unreasonable to assume that there exists a hidden sector, that affects Higgs physics only. Such an extension of the Standard Model involving singlet fields preserves the essential simplicity of the model, while at the same time acting as a realistic model for non–standard Higgs properties. Here we will study the coupling of a Higgs boson to an O(N) symmetric set of scalars, which is one of the simplest possibilities introducing only a few extra parameters in the theory. The effect of the extra scalars is practically the presence of a large invisible decay width of the Higgs particle. When the coupling is large enough the Higgs resonance can become wide even for a light Higgs boson. This has led to the conclusion that this Higgs particle becomes undetectable at the LHC [1]. As one can measure missing energy more precisely at e^+e^-–colliders than at a hadron machine, LEP2 can give important constraints on the parameters of the model. However it is clear that there will be a range of parameters, where this Higgs boson can be seen neither at LEP nor at the LHC. In the next section we will introduce the model together with presently known constraints and in the last section we will discuss exclusion limits at LEP2.

2 The model

The Higgs sector of the model is described by the following Lagrangian,

$$\mathcal{L} = -\partial_\mu \phi^+ \partial^\mu \phi - \lambda(\phi^+\phi - v^2/2)^2 - 1/2\, \partial_\mu \vec{\varphi} \partial^\mu \vec{\varphi} - 1/2\, m^2\, \vec{\varphi}^2 - \kappa/(8N)\, (\vec{\varphi}^2)^2 - \omega/(2\sqrt{N})\ \vec{\varphi}^2\, \phi^+\phi$$

where ϕ is the normal Higgs doublet and the vector $\vec{\varphi}$ is an N–component real vector of scalar fields, which we call phions. Couplings to fermions and vector bosons are the same as in the Standard Model. The ordinary Higgs field acquires the vacuum expectation value $v/\sqrt{2}$. We assume that the $\vec{\varphi}$–field acquires no vacuum expectation value, which can be assured by taking ω positive. After the spontaneous symmetry breaking one is left with the ordinary Higgs boson, coupled to the phions in which it decays. Also the phions receive an induced mass from the spontaneous symmetry breaking. The factor N is taken to be large, so that the model can be analysed in the $1/N$ expansion. By taking this limit the phion mass stays small, but because there are many phions the decay width of the Higgs boson can become large. Therefore the main effect of the presence of the phions is to give a large invisible decay rate to the Higgs boson. The invisible decay width is given by

$$\Gamma_H = \frac{\omega^2 v^2}{32\pi M_H} \quad .$$

The Higgs width is compared with the width in the Standard Model for various choices of the coupling ω in Fig. 1. The model is different from Majoron models [2], since the width is not necessarily small. The model is similar to the technicolor–like model of [3].

Figure 1: *Higgs width in comparison with the Standard Model.*

Consistency of the model requires two conditions. One condition is the absence of a Landau pole below a certain scale Λ. The other follows from the stability of the vacuum up to a certain scale. An example of such limits is given in Fig. 2, where $\kappa = 0$ was taken at the scale $2m_Z$, which allows for the widest range. For the model to be valid beyond a scale Λ one should be below the indicated upper lines in the figure, as otherwise there would appear a Landau pole before this scale. One should be to the right of the indicated lower lines to have stability of the vacuum.

Figure 2: *Theoretical limits on the parameters of the model in the ω vs. M_H plane. Beyond a scale Λ, the physical region is below the indicated upper lines and to the right of the lower lines.*

For the search for the Higgs boson there are basically two channels, one is the standard decay, which is reduced in branching ratio due to the decay into phions. The other is the invisible decay, which rapidly becomes dominant, eventually making the Higgs resonance wide (see Fig. 1). In order to give the bounds we neglect the coupling κ as this is a small effect. We also neglect the phion mass. For other values of the phion mass the bounds can be found by rescaling the decay widths with the appropriate phase space factor. The present bounds, coming from LEP1 invisible search, are included as a dashed curve in Fig. 3 below.

3 LEP2 bounds

In the case of LEP2 the limits on the Higgs mass and couplings in the present model come essentially from the invisible decay, as the branching ratio into $\bar{b}b$ quarks drops rapidly with increasing φ–Higgs coupling. To define the signal we look at events around the maximum of the Higgs resonance, with an invariant mass $m_H \pm \Delta$, with $\Delta = 5$ GeV, which corresponds to a typical mass resolution. Exclusion limits are determined by Poisson statistics as defined in the Interim Report [4]. The results are given by the full lines in Fig. 3. One notices the somewhat reduced sensitivity for a Higgs mass near the Z boson mass and a looser bound for small Higgs masses, because there the effect of widening the resonance is bigger. The small ω region is covered by visible search. There is a somewhat better limit on the Higgs mass for moderate ω in comparison with the $\omega = 0$ case; this is due to events from the extended tail of the Higgs boson resulting from the increased width.

We conclude from the analysis that LEP2 can put significant limits on the parameter space of the model. However there is a range where the Higgs boson will not be discovered, even if it does exist in this mass range. This holds also true, when one considers the search at the LHC. Assuming moderate to large values of ω, i.e. in the already difficult intermediate mass range, it is unlikely that sufficient signal events are left at the LHC. In that case the only information can come directly from the NLC or indirectly from higher precision experiments at LEP1.

Figure 3: *Exclusion limits at LEP2 (full lines), and LEP1 (dashed). The region where ω is small is covered by the search for visible Higgs decay.*

References

[1] T. Binoth, J. J. van der Bij, Quarks 94, Vladimir, Freiburg-THEP-94/26, hep-ph/9409332.

[2] J. Valle et al. LEP2 Report.

[3] R. S. Chivukula, M. Golden, Phys. Lett. B267, 233 (1991).

[4] LEP2 Interim Report, CERN-TH/95-151, CERN-PPE/95-78.